Hot Gas in Bubbles and Superbubbles

You-Hua Chu

Robert A. Gruendl

Martín A. Guerrero

University of Illinois at Urbana-Champaign

Bubbles vs Superbubbles

Single massive star

Fast wind

↓

Bubble

up to a few × 10 pc

Absolutely no SNe!

OB association

Fast winds & SNe

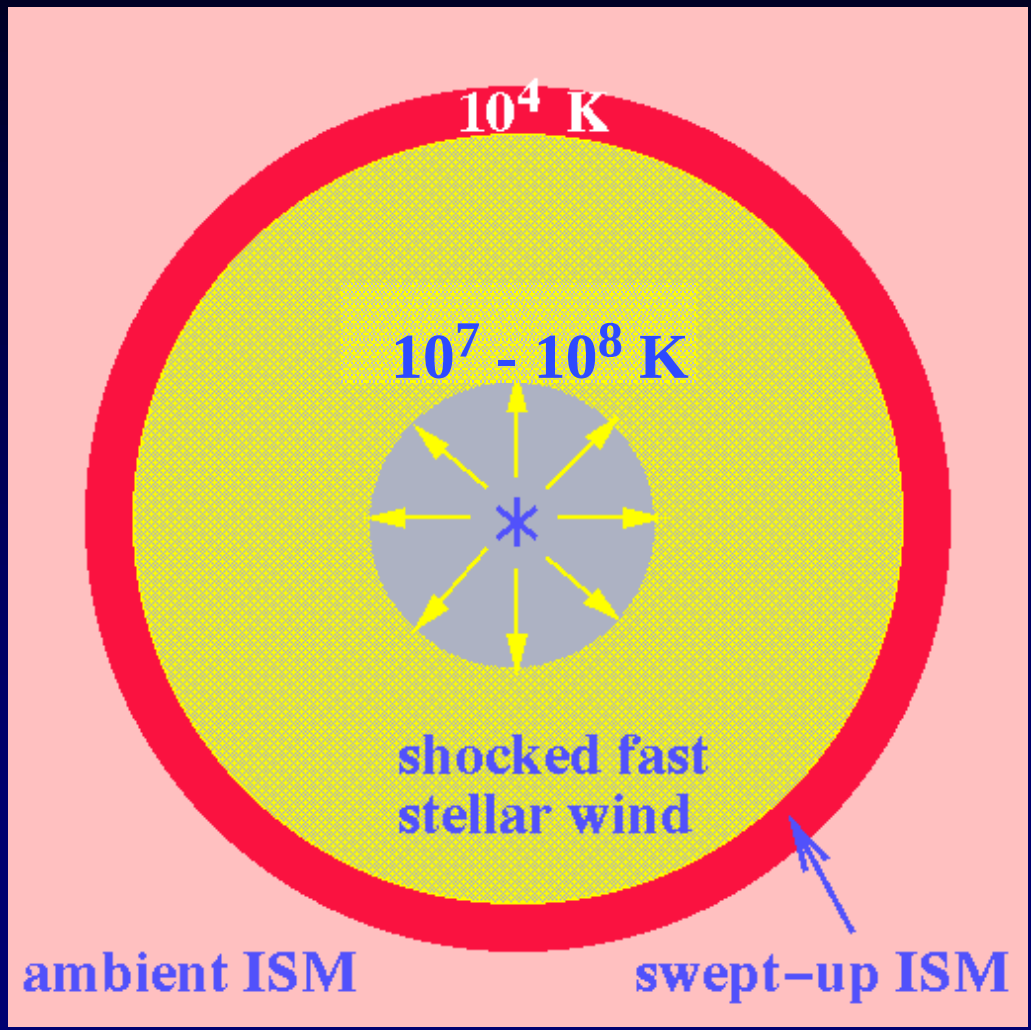
↓

Superbubble

up to a few × 100 pc

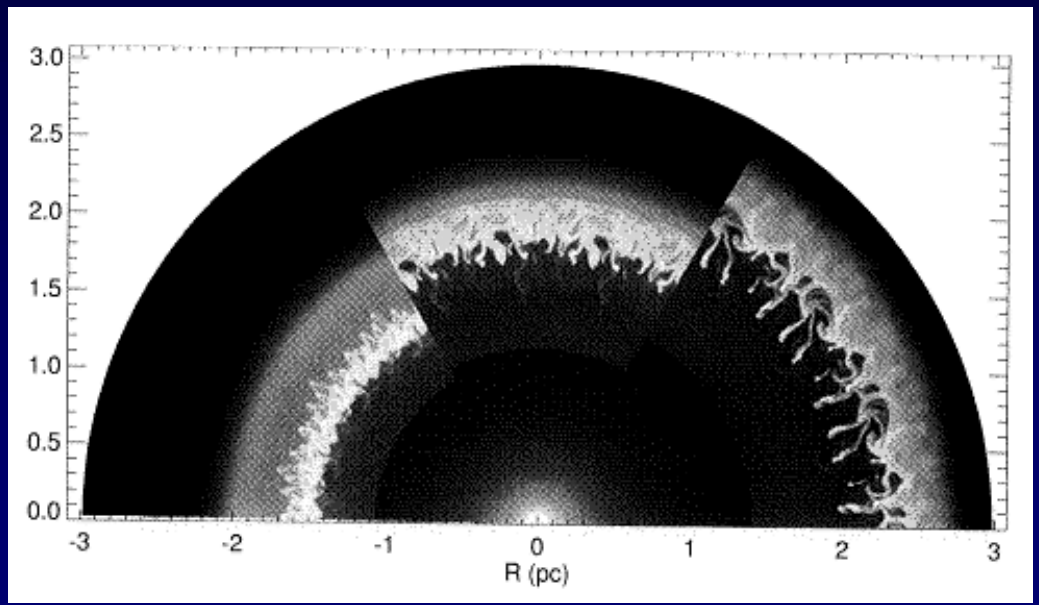
Intermittent SNe.

Interstellar Bubble of a MS Star

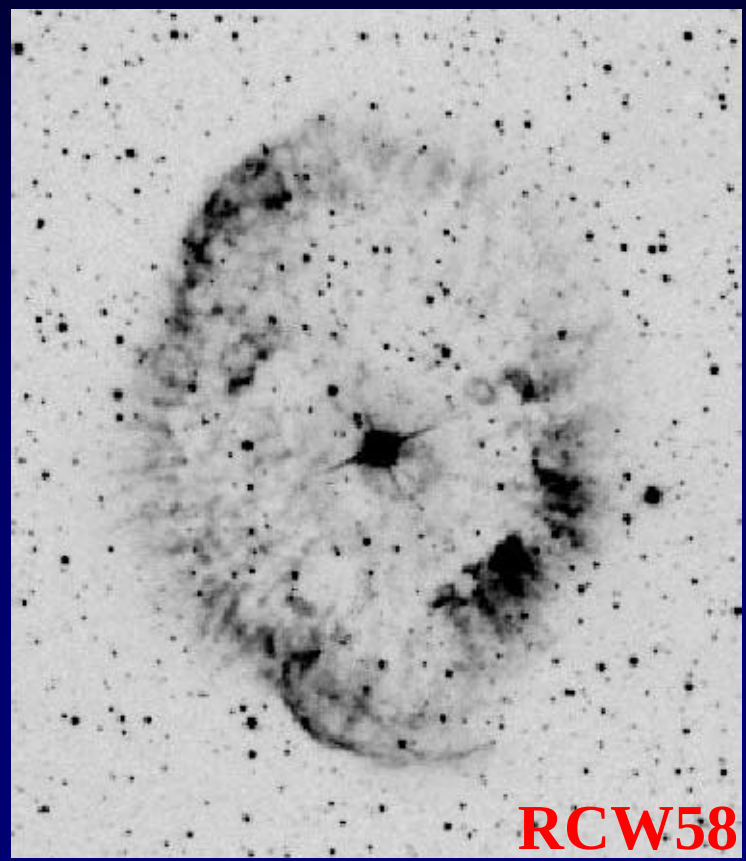


Circumstellar Bubble of a WR Star

Garcia-Segura, Langer, & Mac Low 1996



$O \rightarrow RSG \rightarrow WR$
LBV



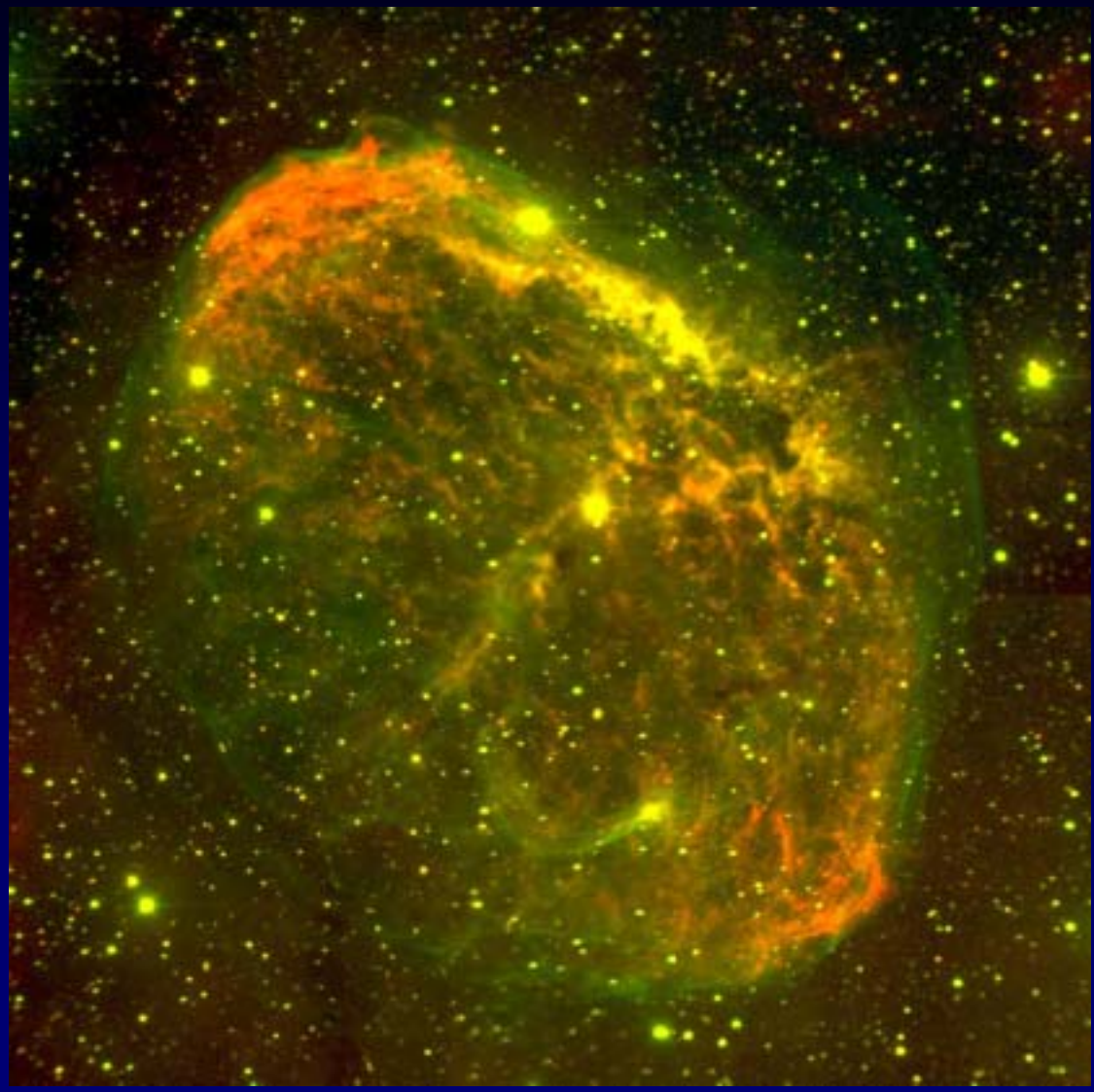
Part I. Hot Gas in Wind-blown Bubbles

Only two circumstellar bubbles of WR stars show diffuse X-rays: NGC 6888 and S308.

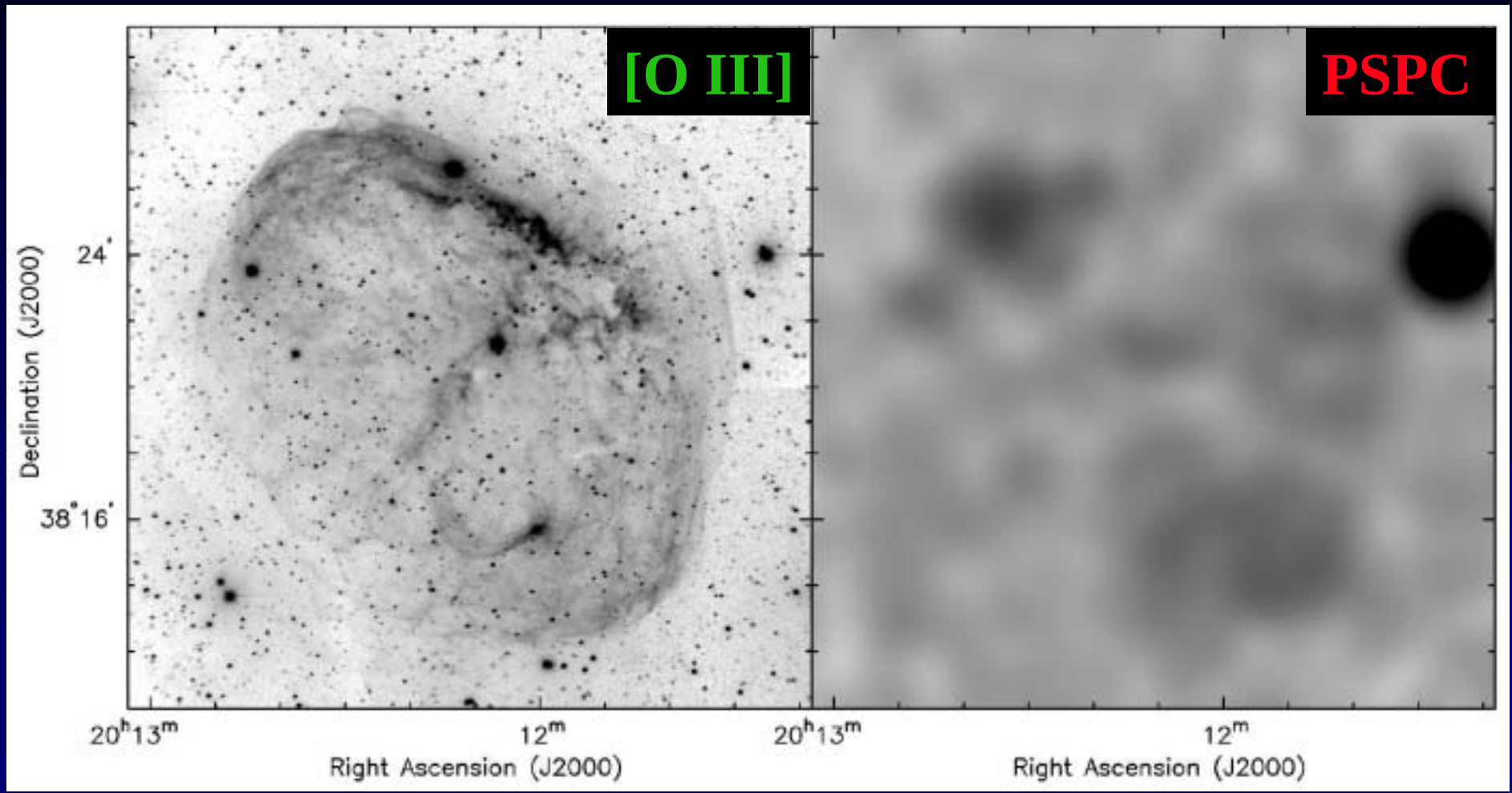
***Chandra* ACIS-S observation of NGC 6888**
***XMM-Newton* observation of S308.**

Comparisons between these circumstellar bubbles and young sperbubbles.

Circumstellar Bubble NGC 6888

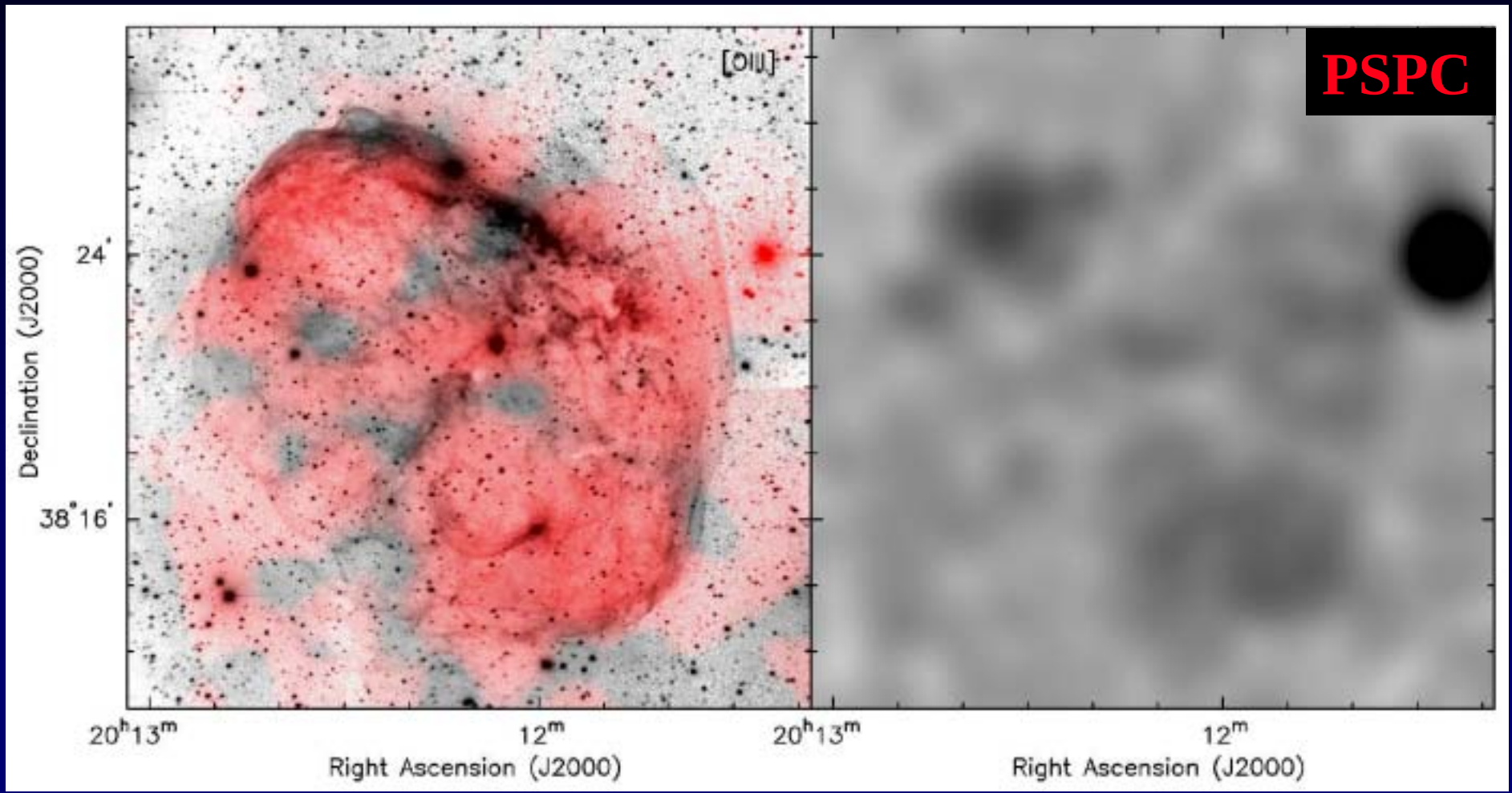


ROSAT PSPC Image of NGC 6888



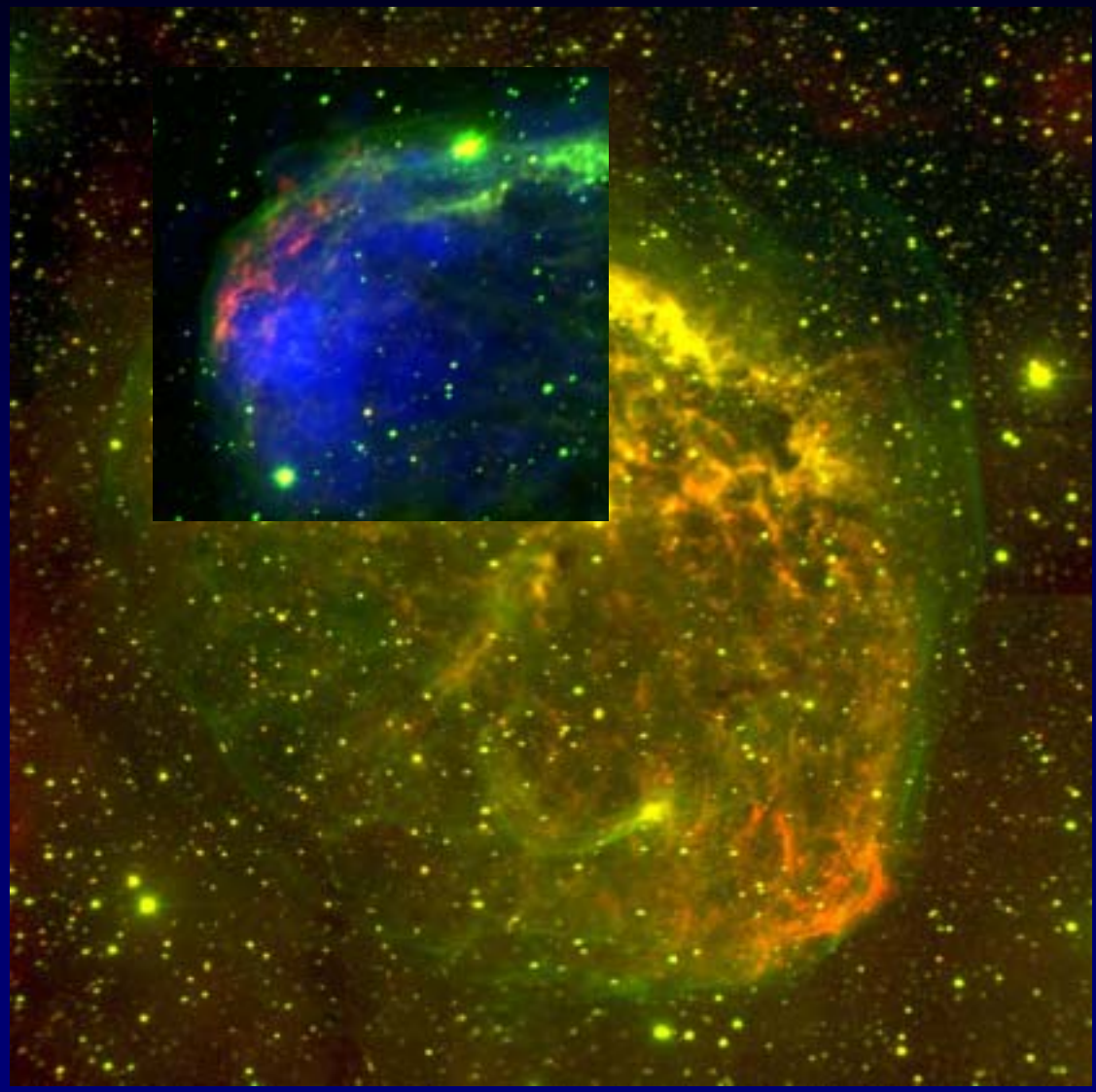
Wrigge et al. 1994, A&A, 286, 219

ROSAT PSPC Image of NGC 6888

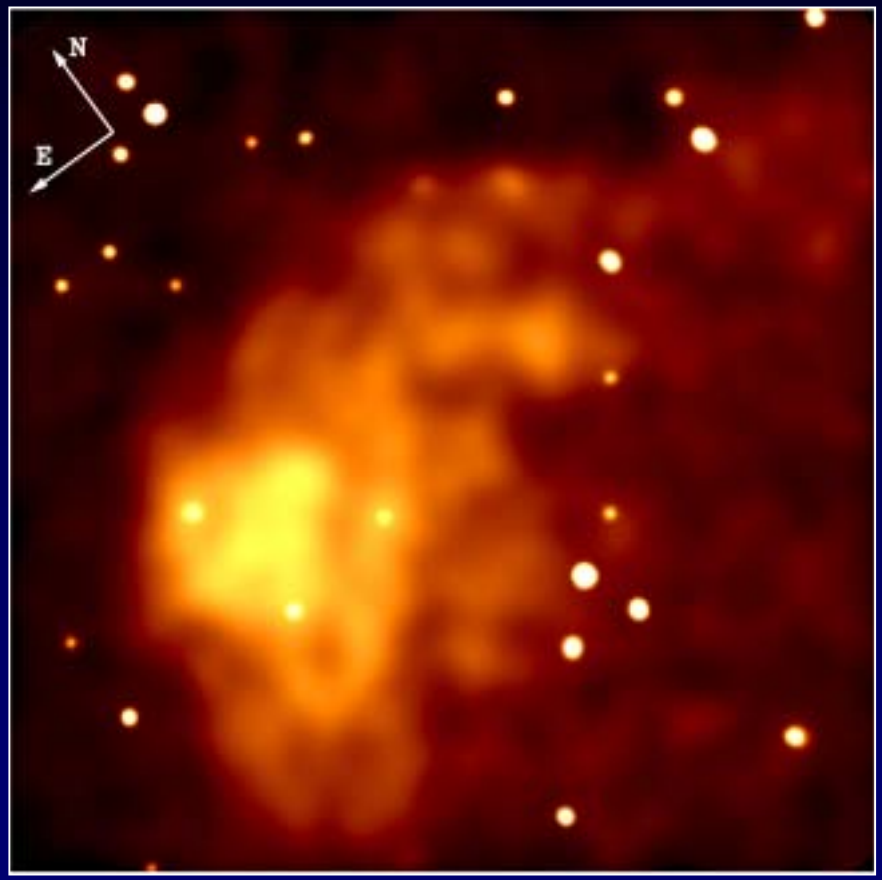


Wrigge et al. 1994, A&A, 286, 219

Circumstellar Bubble NGC 6888



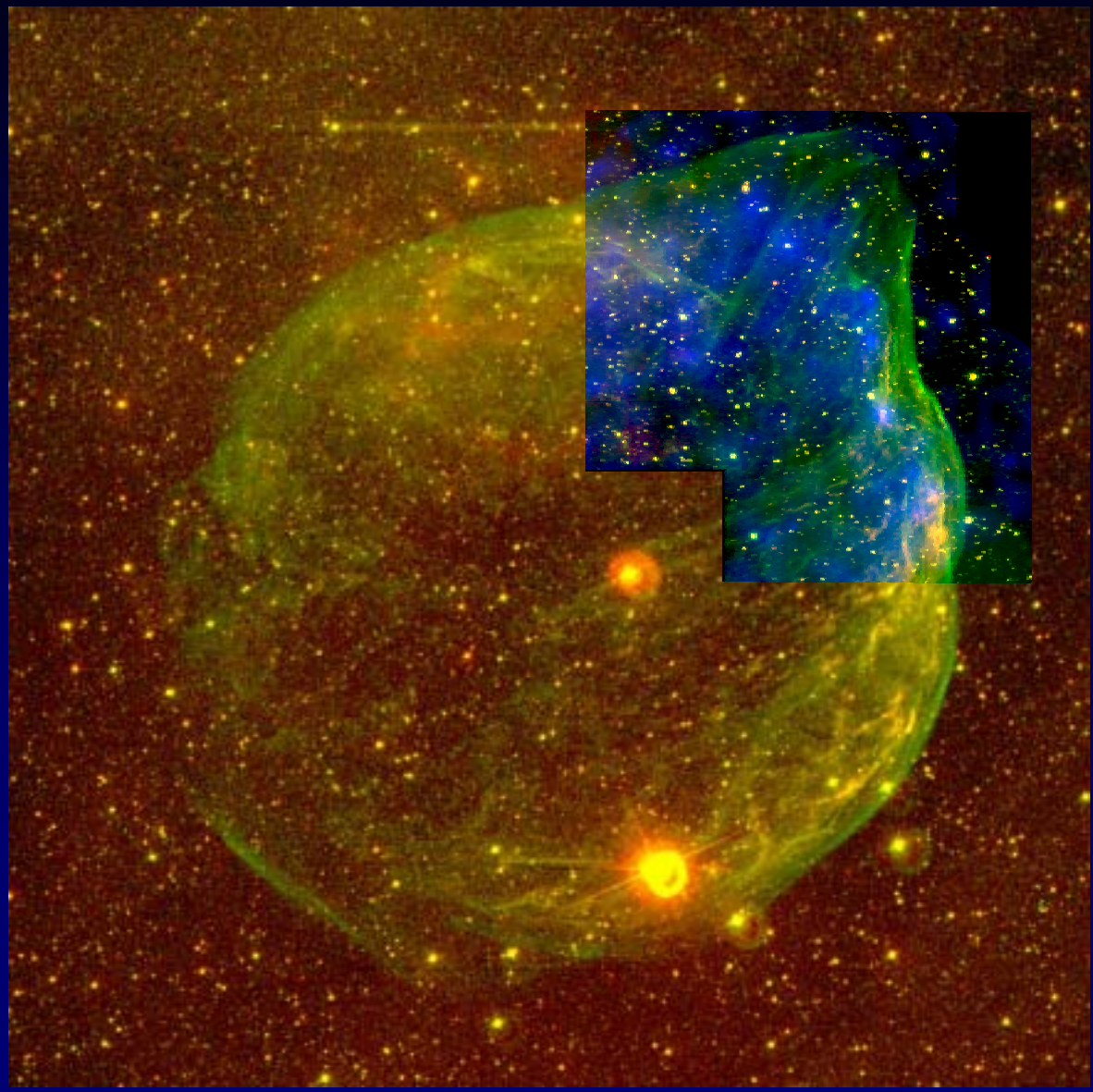
Chandra X-ray Image of NGC 6888



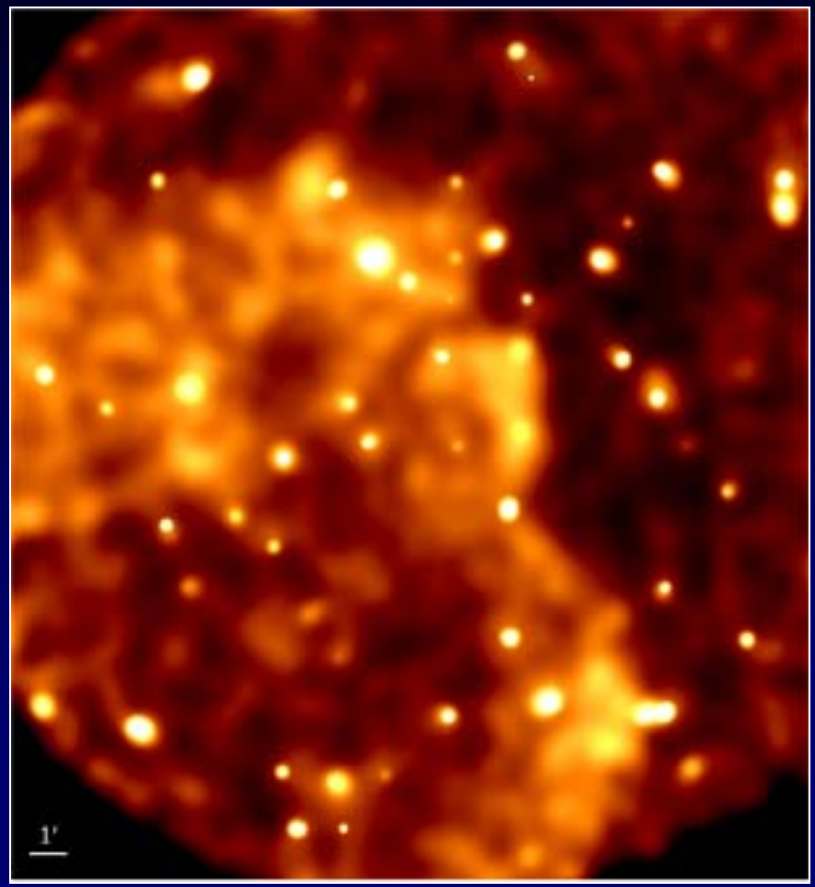
Gruendl, Guerrero, Chu
2003, in prep.

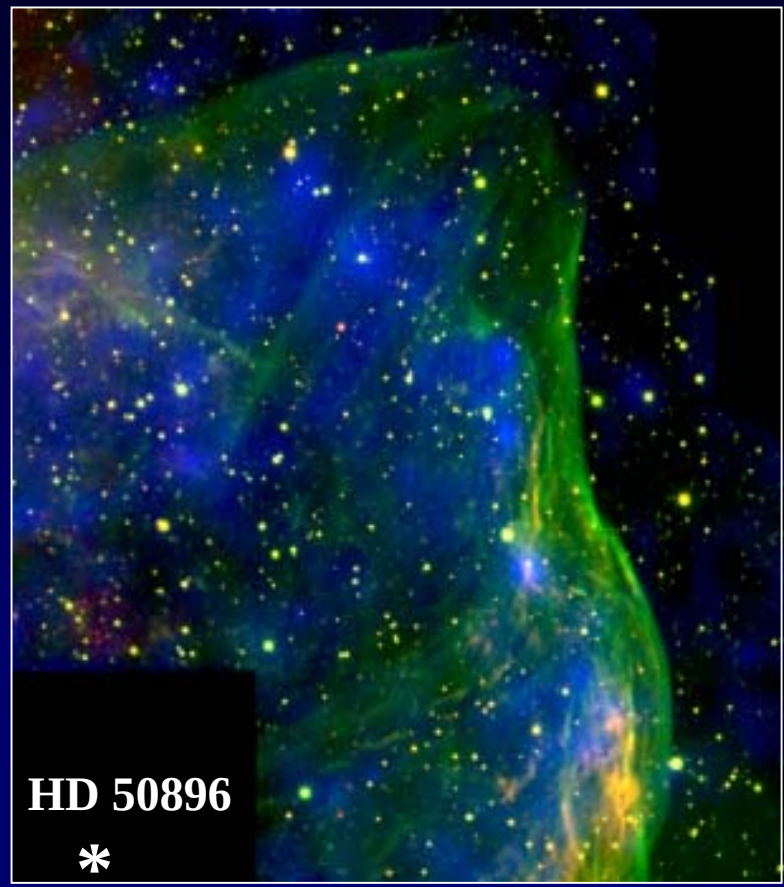
R: Hα G: [O III] B: X-ray

Circumstellar Bubble S308



XMM-Newton X-ray Image of S 308



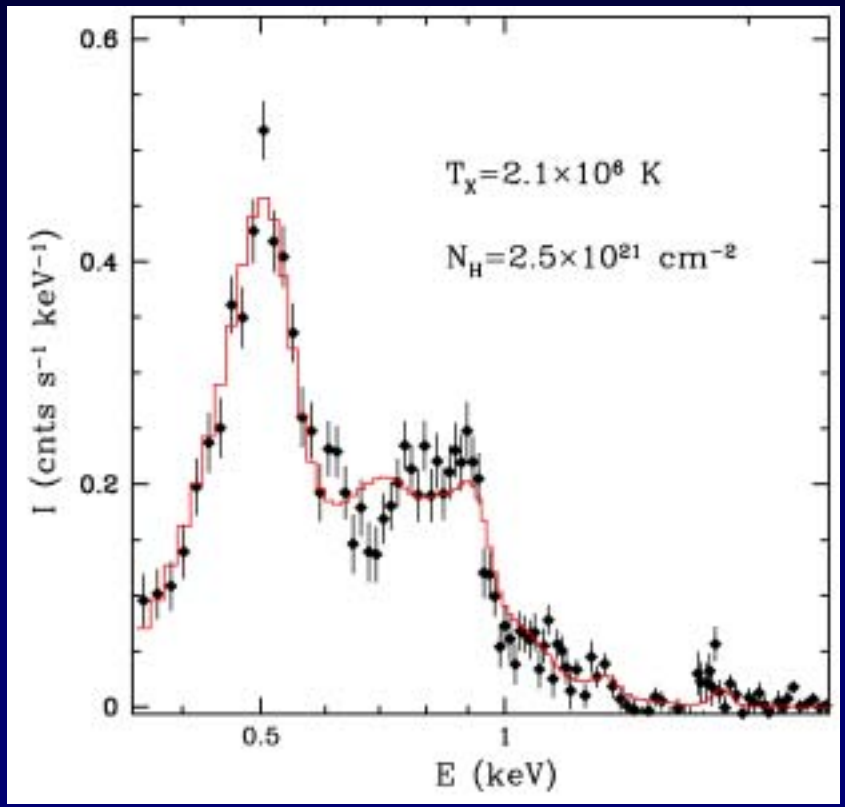


Chu et al. 2003, ApJ, in press

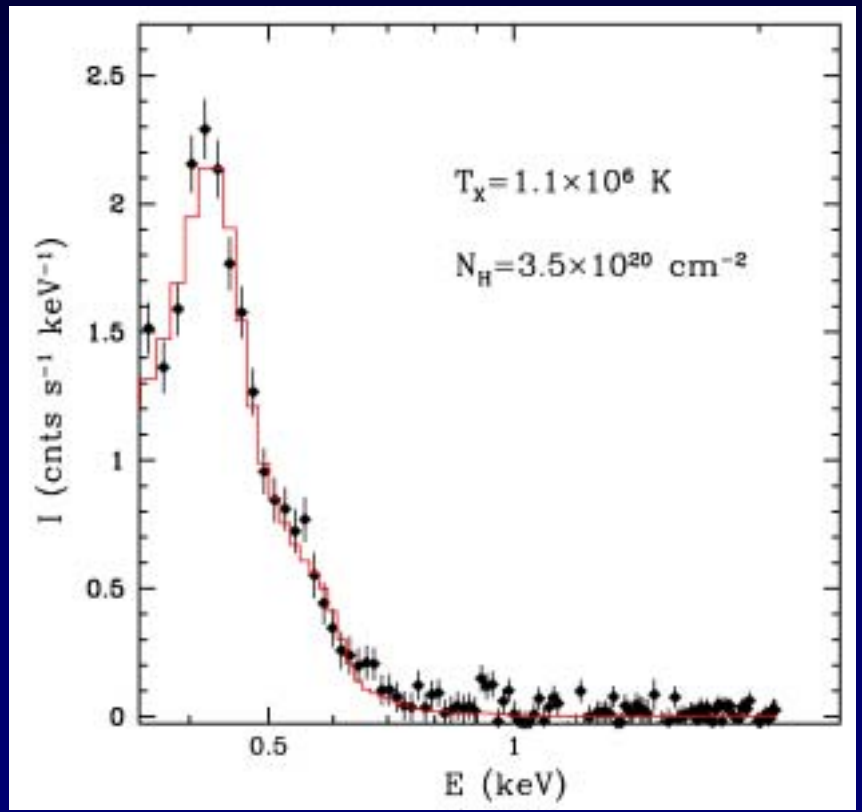
R: Hα G: [O III] B: X-ray

X-ray Spectra of Hot Gas in WR Bubbles

NGC 6888 (ACIS-S)



S 308 (EPIC-pn)



X-rays from Hot Gas in Bubbles

- **Detection of hot gas associated with fast winds**
  - **2 WR bubbles (NGC 6888, S308)**
  - **2 young superbubbles & 2 HII regions**

- **Properties of the hot gas:**

	T_e [10^6 K]	N_e [cm^{-3}]	L_X [erg/s]
WR	1-2	1	$10^{33} – 10^{34}$
SB/HII	10	0.1	10^{33}

- **Interface layers resolved in WR bubbles?**

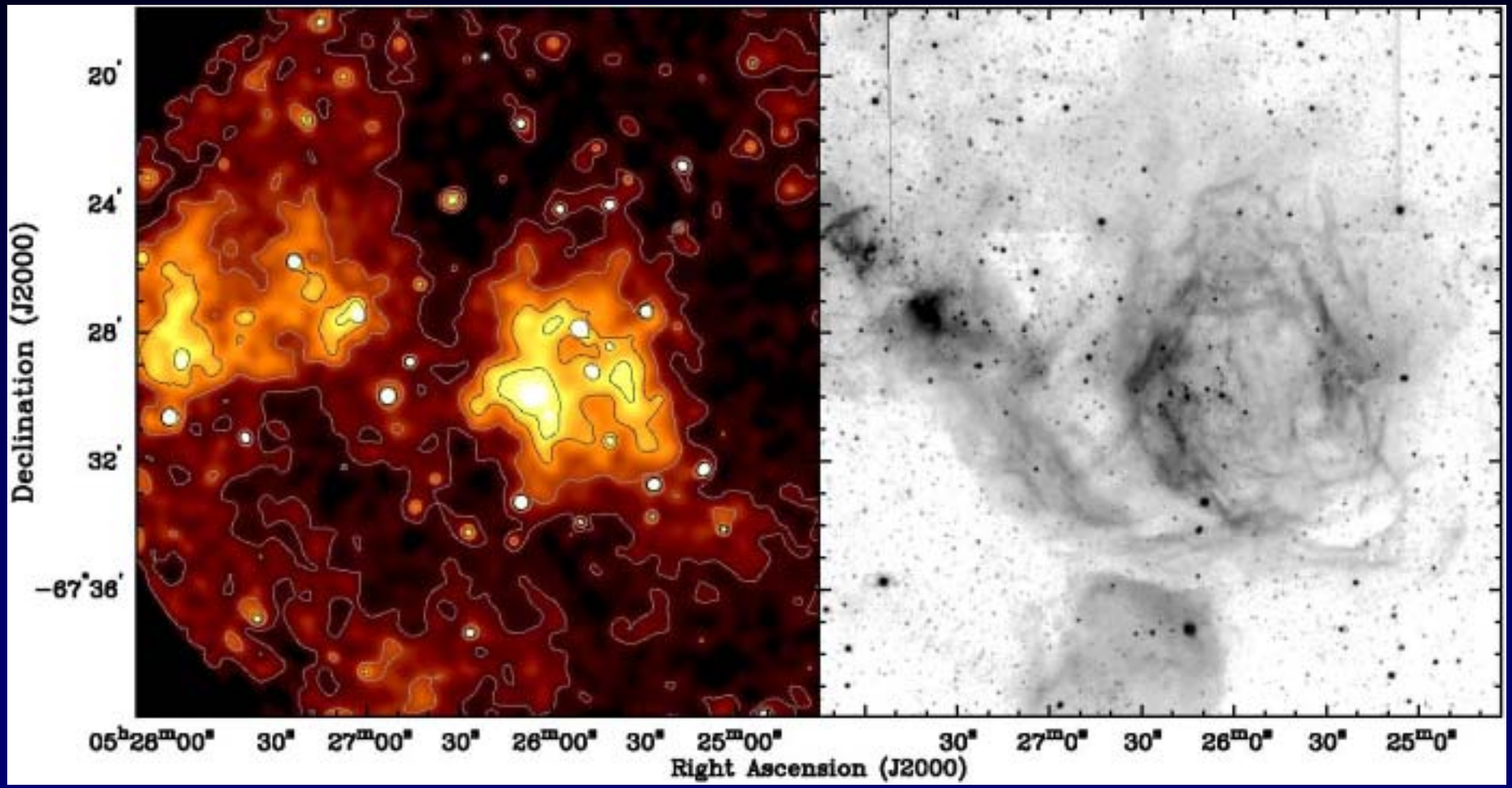
Part II. Energy Crisis in a Superbubble

Superbubbles are excellent sites to study stellar energy feedback.

Stellar mechanical energy (fast winds + supernovae) is converted into kinetic and thermal energy in the surrounding ISM.

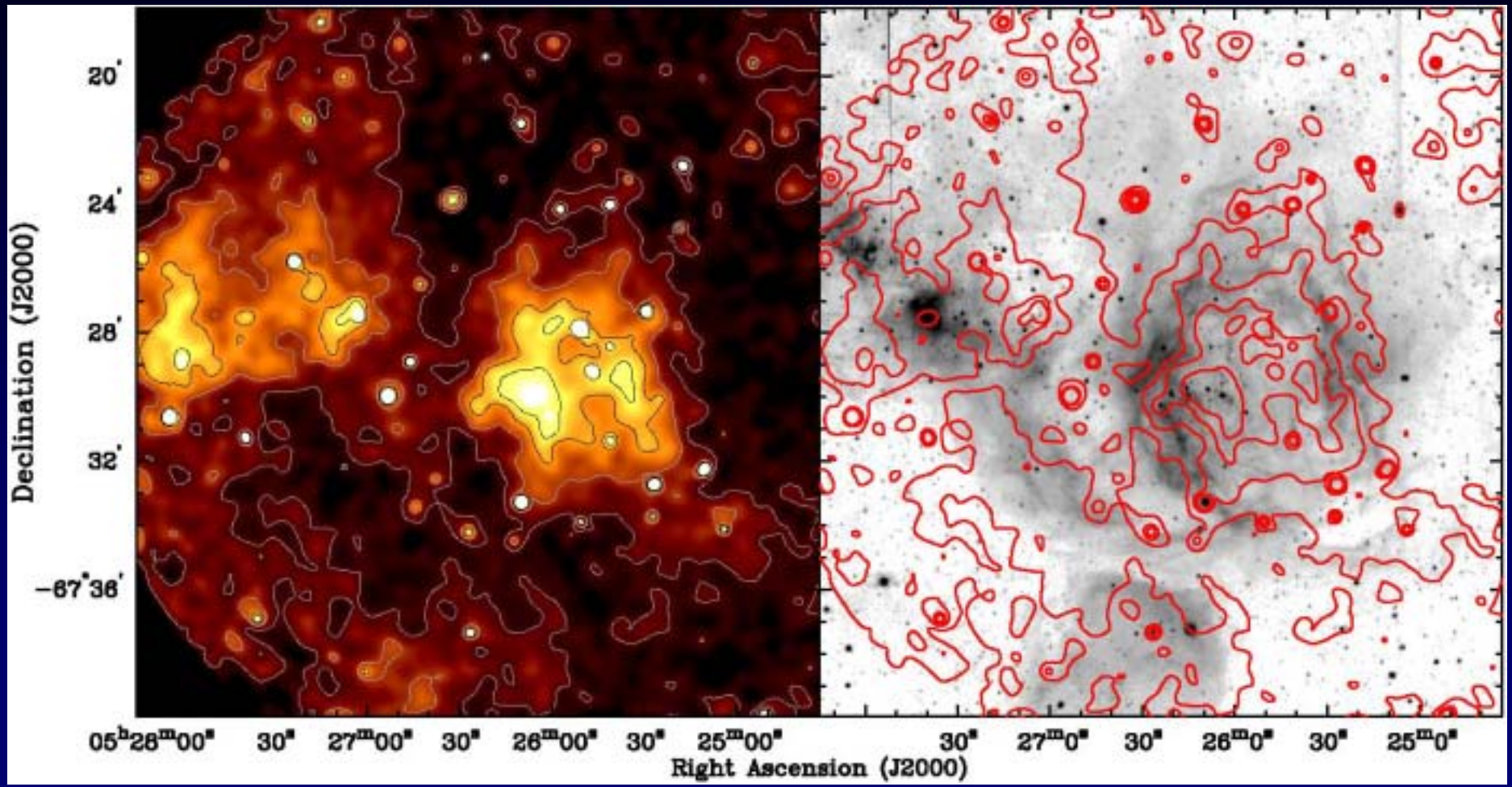
Energy crisis in the LMC superbubble N51D.

N51D: a Superbubble in the LMC



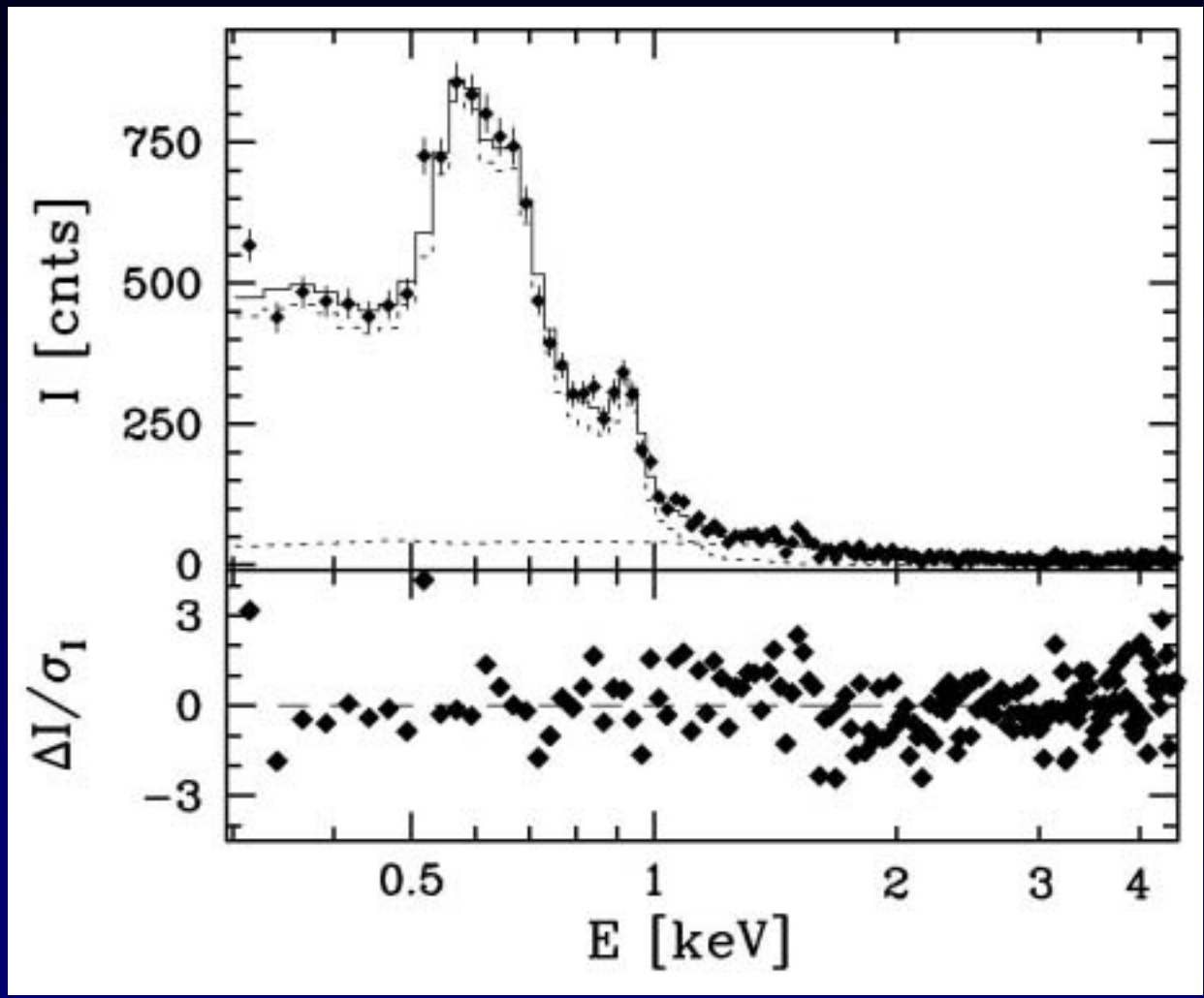
Cooper et al. 2003, to be submitted

N51D: a Superbubble in the LMC



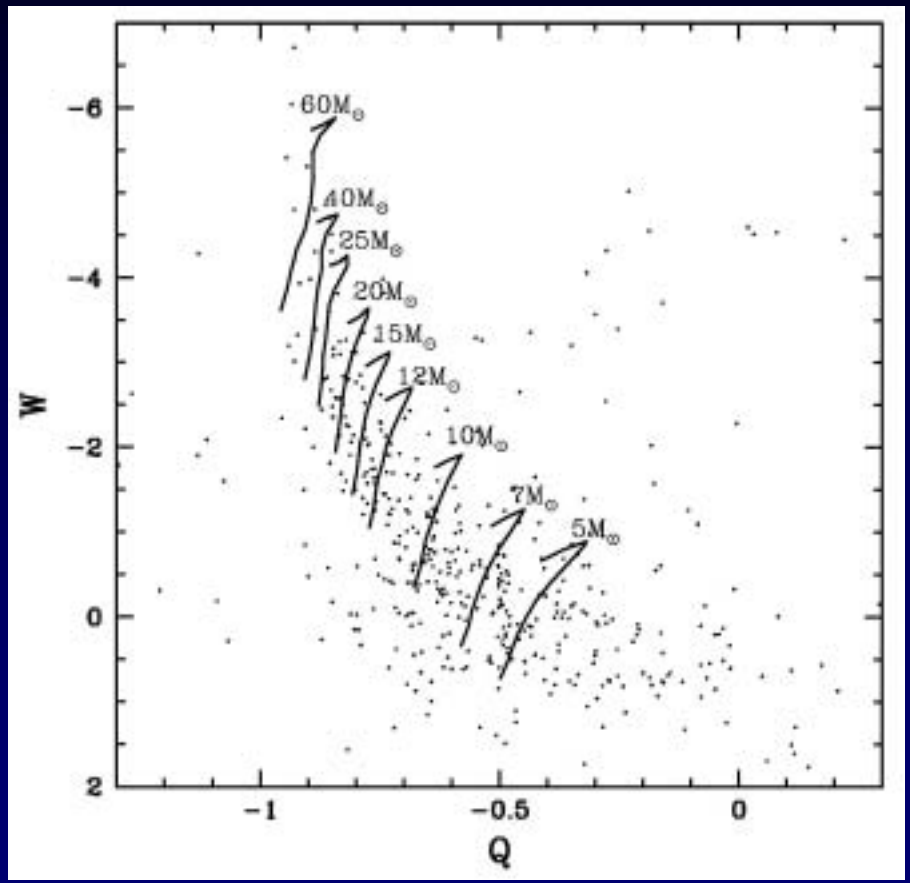
Cooper et al. 2003, to be submitted

XMM EPIC Spectrum of N51D



0.2 keV thermal + power-law

Stellar Content of N51D



Extinction-free CMD using photometry by Oey (1996)

UBV photometry

↓

Color-Magnitude diagram

↓

Mass function of B dwarfs

↓

Salpeter IMF

↓

Stellar winds supernovae

Energy Crisis in Superbubble N51D

E_{th} of hot interior	$1.1 \pm 0.5 \times 10^{51}$ ergs
E_{kin} of HII shell	$1.4 \pm 0.4 \times 10^{51}$ ergs
E_{kin} of HI shell	$3.0 \pm 0.5 \times 10^{51}$ ergs
E_{total}	$5.5 \pm 1.5 \times 10^{51}$ ergs

E (stellar winds)	$3 \pm 1 \times 10^{51}$ ergs
E (supernovae)	$15 \pm 5 \times 10^{51}$ ergs
E (total stellar)	$18 \pm 6 \times 10^{51}$ ergs

Where did the stellar energy go?

Summary and Conclusions

- **Chandra and XMM-Newton reveal exciting hot gas in (super)bubbles!**
  More observations are needed, please award more time to (super)bubbles.
- **Multi-wavelength observations show discrepancy with bubble theories.**
  Future models need to consider detailed plasma physics.